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EFFECT OF COMBUSTOR INLET TEMPERATURE AND FLAME STABILIZER PRESSURE LOSS ON WEAK EXTINCTION CHARACTERISTICS OF PREMIXED FLAMES

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ABSTRACT

A can combustor was used to study the weak extinction characteristics of premixed swirling flames associated with two operating parameters, i.e. combustor inlet temperature and flame stabilizer pressure loss. The combustor was 76 mm in diameter and tested at a constant Mach number. High inlet temperature combustion was simulated using preheat air and variation in pressure loss across the flame stabilizer was accomplished by testing different swirler configurations. The test results show that increasing the combustor inlet temperature significantly widened the flame stability margin due to the increased shear layer ignition temperature. Increasing the flame stabiliser pressure loss improved the fuel distribution in the stabilising shear layer and consequently retarded the extension of the flame stability margin.

ABSTRAK

Pembakar berbentuk silinder digunakan untuk mengkaji ciri-ciri pemadaman lemah bagi nyalaan pracampur pusar. Dua parameter kendalian, ia itu suhu suapan pembakar dan kehilangan tekanan penstabil nyalaan disiasat. Pembakar bergarispusat 76 mm dan diuji pada keadaan Mach nombor yang malar. Pembakaran pada keadaan suhu suapan yang tinggi dicapai dengan menggunakan udara prapanas dan perubahan kehilangan tekanan dicapai dengan menguji tatarajah pemusar yang berlainan. Keputusan ujian menunjukkan penambahan suhu suapan pembakar berjaya melebarkan jidar kestabilan nyalaan. Ini disebabkan oleh penambahan suhu pencucuhan lapisan ricih. Penambahan kehilangan tekanan memperbaiki taburan bahan api di dalam lapisan ricih penstabilan dan ini merencatkan pemanjangan jidar kestabilan nyalaan.

INTRODUCTION

One of the primary requirements of a gas turbine combustor is that combustion must be maintained over the whole range of operating conditions, including the transient state of rapid acceleration and deceleration. The term "stability" is often used to describe either the range of fuel-air over which stable combustion can be achieved, or as a measure of the air velocity over which the system can tolerate before flame extinction or flame blowoff occurs. The primary zone combustion stability characteristics are important as it ensures high combustion efficiency required for low emissions to be achieved.

Most of the previous work on the mechanism of weak extinction has been concentrated on bluff body systems. These systems involve relatively large recirculation zones and have generally involved test data relevant to reheat system with a low flame stabiliser blockage and high mean velocities. One of the early work from the aerodynamic viewpoint was carried out by Zulkowski (Zulkowski et al, 1955). They concluded that ignition of the fresh mixture in the shear layer was induced by the hot combustion products entrained therein from the recirculating zone. Work by Longwell (Longwell et al, 1953) on bluff body flame stabilization found that flame extinction occurred when the time available for chemical reaction became less than the time required to generate sufficient heat to raise the ignition temperature of the fresh mixture. A proper control of flow or turbulence velocity has recently been extensively related to the weak extinction phenomena. The early theory is that flame extinction occurs when a turbulence velocity exceeds a flame propagation or burning velocity (Beer et al, 1972). A further work based on this theory has been carried out by several researchers (Kalghatgi, 1981 and Andrews et al, 1984). Another method of stabilising flames, as proposed by Zulkowski et al, is to create local fuel-rich zones in the shear layer through which fresh combustibles are ignited by the entrained hot combustion products from the outer part of the shear layer. The present work has been based on this theory.

EXPERIMENTAL APPARATUS AND TEST PROCEDURES

The atmospheric pressure test rig consists of a 330 mm long 76 mm diameter uncooled can combustor, air feed blower, electrical air preheater, orifice metering device, 1.5 m long 76 mm diameter approach pipe and mean sample probe. There is also a 152 mm water cooled exhaust pipe with an observation window on the combustor center line. A schematic layout of the test rig si shown in figure 1. The combustor was also equipped with wall pressure tappings and thermocouples.

Combustion air and fuel were supplied by an air blower via a 42 mm-diameter orifice meter and a rotameter, respectively. Inlet and outlet, wall temperatures and static pressure were monitored by an electronic micromanometer and were recorded in the data acquisition system. The preheat air was introduced in the primary zone through a 45^{o} blade angle radial swirler. Air and fuel were partially premixed in the swirler vane passage prior to entering the primary zone.

The tests were carried out a constant Mach number (M). M is defined as the ratio of the mean flow velocity to the velocity of sound, as given by the equation below;

$$M = V/(\gamma RT) \qquad (1)$$

where U is the mean flow velocity in m/sec, R is the gas constant for air in J/KgK, T is the inlet temperature and γ is the specific heat ratio. The Mach number (hence the mean flow velocity), pressure loss (dP/P) and combustor inlet temperature (T) are correlated by the following equation;

$$dP/P = (1/2RT)(U/C_D)^2(A_1/A_2)^2=(\gamma/2)\{(MA_1)/(C_DA_2)\}^2 \qquad (2)$$

where A_1 is the upstream pipe flow area, A_2 is the combustor flow area and C_D is the flame stabilizer discharge coefficient. The pressure loss is defined as the ratio of pressure drop across of the flame stabilizer to the combustor inlet pressure.

The air was heated to the required combustor inlet temperature by an electrical heater. The inlet temperature was measured using a chromel-alumel K thermocouple mounted 100 mm upstream the flame stabilizer. Variation in pressure loss was obtained by testing different swirler configurations. The swirler design geometry is given in table 1.

RESULTS AND DISCUSSION

i) Influence of combustor inlet temperature

Weak extinctions were determined at a constant Mach number and pressure loss of 0.03 and 2.7%,respectively and at a preheat inlet air temperature of either 400 K, 600 K, 740 K or 900 K by gradually reducing the fuel flow until the flame was finally extinguished. The process was observed directly from the control room through a 100 mm diameter observation window. The weak extinctions were also easily observed by a sudden increase in unburnt hydrocarbon (UHC) emissions.

The measured weak extinction results as a function of metered equivalence ratio presented in Figure 2. The test results show that increasing inlet air temperature from 400K to 900K reduced the weak extinction equivalence ratio from 0.5 to 0.25 for natural gas and from 0.44 to 0.22 for propane, thus widening the weak extinction region by 50%. This signifies a continual improvement in the flame stability characteristics as the combustor inlet temperature increases. The reason for this improvement could be explained by referring to Equation 3 which correlates the rate of fuel and air mixing, e, taken as equivalent to the rate of energy dissipation per unit mass to the pressure loss parameter and combustor inlet temperature (Andrews et al, 1988).

$$e = C \frac{dP}{P} T^{1.5} \frac{1}{L} \qquad (3)$$

where C = constant , dP/P = flame stabilizer pressure loss, T = combustor inlet temperature and L = turbulence scale.

As the combustor pressure loss was kept constant (and therefore constant turbulence intensity associated with pressure loss and Mach number) increasing the inlet temperature increased the energy of the air jet entering the stabilising shear layers. This resulted in an increase in the shear layer temperature and hence provided a better ignition source and a rapid acceleration of burning velocity of adjacent flame elements within the high temperature stabilizing shear layers. As a consequence the operation was extended to an even leaner mixture.

The above discussion is further supported by the development of combustor wall temperature profiles for natural gas combustion as shown in Figure 3 (a-d). Comparison of temperature shows that as the combustor inlet temperature was steadily increased the rate of flame propagation was much faster and the main region of heat release was also much closer to the swirler outlet. This was mainly due to the reason as discussed earlier.

ii) Influence of flame stabilizer pressure loss

The pressure loss used in the correlation of the weak extinction data , known as "cold pressure loss" was the pressure loss due to the flame stabiliser blockage. This type of pressure loss is undesirable since it reduces the cycle network and consequently gives a high specific fuel consumption. The variation in pressure loss was accomplished at a constant inlet temperature and Mach number using two swirlers, A and B, with different upstream pipe flow area, A_1 (and therefore A_1/A_2 ratio).

Figure 4 illustrates the effect of varying the combustor pressure loss from 2.7% to 3.4%-3.7% on the weak extinction equivalence ratio for propane. For the same inlet condition an increase in pressure loss by 0.7%-1.0% increased the weak extinction equivalence ratio by 5%-25%. This shows that increasing the degree of flow expansion just downstream the flame stabilizer outlet is not favourable to the extension of the weak extinction limit. As shown in Equation (3), increasing the stabiliser pressure loss at a fixed inlet temperature improved the rate of fuel and air mixing. The more uniform distribution of fuel in the stabilizing shear layers as a result of the increased turbulence level with the pressure loss created less fuel rich stabilising zones and the rate of flame propagation was retarded as a consequence.

iii) Comparison of propane and natural gas

The weak extinction characteristics of propane appear to be slightly better than that of natural gas. This was possibly because the lower molecular weight of natural gas allowed gas molecules to disperse faster in the high temperature air flow. The rapid fuel-air mixing produced less local rich mixtures in the stabilizing shear layers and consequently reduced the flame stability margin.

CONCLUSION

1. Increasing the combustor inlet temperature significantly widened the weak extinction limit and hence allowed an operation at an even lower value of equivalence ratio.

2. Increasing the flame stabiliser pressure loss created less fuel rich stabilising shear layer and consequently retarded the extension of the flame stability margin.

3. Propane had better flame stability margin as compared to natural gas.

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